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Multi-criteria analysis of alternative biogas technologies

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Abstract

The need for reliable and renewable energy sources is increasing day by day and with it is the revived interest in the biogas technology, especially when addressing rural cooking and lighting energy needs. MNRE, which is the nodal agency for all biogas programmes, has been promoting around 15 biogas models. However, there is no documentation available on how the models are approved thus, leaving the choice of model to the end users. This has resulted in promotion of the models based on the organisation's (governmental and non-governmental) expertise in constructing certain models rather than the informed choice of the end user. One of the answers to these questions, is a multi-criteria decision making tool which can aid in the promotion of different biogas technologies on the basis of several socio-economic-environmental criteria maybe able to address these questions. The tool can be used to make the decisions from various perspectives e.g the government, the NGOs, the users, etc. This study undertakes an analysis based on the Analytical Hierarchical Process (AHP) tool for biogas technologies being promoted by GOI with a perspective of overall self reliance of the country. A case study approach has been illustrated for a small biogas plant of 2 m^3 with a perspective of sustainable development. A total of 17 attributes, both quantitative and qualitative, have been used in a two level hierarchy to carry out the AHP.

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Keywords: Biogas Technology; NBMMP; Analytical Hierarchy Process; Multi-criteria decision; Biogas Policy

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1. Background

In today's era of fuel crisis, higher fossil fuel prices, energy security and environmental concerns, nuclear disasters; need for reliable and renewable energy sources is expected to expand. There is a revived interest in the biogas technology especially when addressing rural cooking and lighting energy needs. Biogas technology uses the anaerobic digestion process and is an attractive fuel option as it generated from inexpensive source, compatible with smokeless urban cooking practices like LPG (Liquefied Petroleum Gas), and reduces time and efforts in collecting firewood. Biogas technology also provides fertiliser after anaerobic digestion that has superior nutrient qualities over the usual organic fertiliser, cattle dung [1] while, also functioning as a waste disposal system, particularly for human waste and preventing potential sources of environmental contamination and the spread of pathogens [2].

Development of biogas technology in India began more than seventy years ago and floating dome plants promotion began in 1962 by Khadi and Village Industries Commission (KVIC). A low cost fixed dome plant called "Deenbandhu" based on the Chinese model was developed by Action for Food Production (AFPRO) and released for extension in 1984. Through the efforts of state government agencies, KVIC, AFPRO and other extension agencies, plants were set up all over India. The National Project on Biogas Development (NPBD) was launched by Government of India in 1982, which accelerated the promotion of popular and approved models of biogas plants including; (i) floating gasholder type, popularly known as "KVIC Model" and (ii) fixed dome type, commonly known as "Deenbandhu Model".

During the 11th Five year Plan (2007-2012), the Government of India has sanctioned a financial outlay of the order of the 5600 million INR for implementing the centrally sponsored scheme – National Biogas and Manure Management Programme (NBMMP) in all States and Union Territories. India's potential of household biogas plants is estimated at 12 million and till December 2010, around 4.27 million have been constructed. The "Strategic Plan for new and renewable energy sector for the period 2011-17" has set targets of additional 1.1 million plants.

With issues of climate change taking a forefront there is a need to promote technologies like biogas which effectively addresses the problem of greenhouse gas emissions and solid waste management. This will lead to self-reliant development of a country by meeting the energy needs through renewable sources, and decentralised energy supply in domestic, industrial and commercial segments in rural and urban areas. MNRE, which is the nodal agency for all biogas programmes, has been promoting around 15 biogas models (see Table 1). However, there is no documentation available on how these models were approved. Also, there are basically just two technologies i.e. fixed dome (fixed volume varying pressure) and floating dome (fixed pressure varying volume) being promoted (except for the Bag Type). Most of the new models being promoted are pre-fabricated models with either RCC, HDPE or FRP as the material of construction. Thus, the choice of model is left to the end users who many a times are not well-informed. This has resulted in promotion of the models based on the promoting organisation's (governmental and non-governmental) expertise in constructing certain models rather than the informed choice of the end user. This study stems from the following questions:

- Which of the models being promoted are the best, keeping the perspective of sustainable development of the country and success of the NBMMP as the primary focus?
- Should there be an evaluation of any newer models being added to the list of promoted models, so as to ascertain the model's capability? If yes, then what should be the criteria for evaluation and what techniques can be used to carry out such an evaluation?
- What criteria should be used by the end user for selection of a model from the list of models being promoted by the government?

The selection of any technology is usually done on the basis of several techno-economic considerations. In addition, local and global level scenarios also necessitate the consideration of some environmental and social factors. One of the answers to these questions, is a multi-criteria decision making tool which can aid in promotion of different biogas technologies based on socio-economic-environmental criteria. The tool can be used to make the decisions from various perspectives e.g the government, the NGOs, the users, etc. The current study carries out a multi criteria analysis based on Analytical Hierarchical Process (AHP) tool for biogas technologies being promoted by the Government of India with a perspective of overall self-reliance. A case study for small biogas plant is illustrated with a perspective of sustainable development, the study provide ranking of different biogas technologies useful from the government, NGOs, users, perspectives to arrive at the right choice.

Table 1. Models promoted by the MNRE.

Nos	Models Types
	Pre-fabricated Biogas Plants model:
1	Pre-fabricated RCC fixed dome model
2	Pre-fabricated RCC digester KVIC family type model
3	Pre-fabricated HDPE material based complete Deenbhandhu Model
4	Pre-fabricated BIOTECH make FRP Model
5	Pre-fabricated HDPE material based KVIC type floating dome Biogas Plants.
6	Shakti-Surbhi FRP based floating dome KVIC design by Vivekanand Kendra
7	Sintex make plastic based floating dome KVIC type biogas plant , by Sintex Industries Ltd.
	Floating Dome Type Biogas Plants:
8	KVIC floating metal dome type Biogas Plants
9	KVIC type plant with Ferro Cement digester and FRP gas holder
10	Pragati Model Biogas Plants
11	Bag Type Biogas Plants (Flexi model)
	Fixed Dome Biogas Plants:
12	Deenbandhu Model with Brick masonry
13	Deenbandhu ferrocement model with in-situ technique
14	Prefabricated HDPE material based prefabricated dome for Deenbandhu family size model
15	Solid -State Deenbandhu design fixed dome biogas plant by ICAR

2. Analytical hierarchy process

Analytical Heirarchy Process (AHP) developed by Prof. Thomas Saaty in 1970s is a structured scientific tool which aids in understanding and analysing diverse information about various technologies and arrive at a right technology option. AHP is quite popular because of its utility and outweighs other rating methods [3, 4]. Various researchers in the field of biogas and energy have used AHP as a tool. Strojniski and Vestnik [5] have used AHP to assess suitability of energy crops for processing into biogas while Simeoni and Alessandro [6] have used AHP to choose the priority of financing different renewable energy plants where one of the renewable energy plants identified was biogas plant. Kablan, [7] has used AHP to support management in the prioritization process of policy instruments for promoting energy conservation while Yong and Wenzhe [8] have analysed factors which influence the extended application of rural biogas technology.

AHP provides a comprehensive and rational framework for structuring a decision problem, for representing and quantifying its elements, for relating those elements to overall goals, and for evaluating alternative solutions. AHP provides a pair-wise comparison method for arriving at weights and also a measure for consistency of pair-wise comparisons. AHP also helps in quantifying the qualitative attributes. Another important advantage of the AHP is in structuring a decision problem into a number of hierarchical levels. Because of these advantages the AHP is chosen for analyzing the technology alternatives in this paper.

3. Research methodology

3.1. Biogas technologies identification and data collection

For the current study, six biogas technology alternatives were selected for analysis including, KVIC digester (T1), KVIC digester with ferrocement digester (T2), KVIC digester with FRP gas holder (T3), KVIC digester with FRP digester and gas holder (T4), which belong to floating dome type and Deenbandhu (T5) and bi-phasic digester based on Nisargaruna technology (T6) belonging to fixed dome type biogas plant. While technologies T1 to T5 are promoted by the MNRE, technology T6 is a newly developed model by the Bhabha Atomic Research Centre (BARC). For evaluation a '2 m^3 capacity' biogas model which is mostly promoted for small households with 1-2 cattle and is suitable for rural areas has been identified / shortlisted and information regarding the technical, social, economic and environmental attributes were obtained through primary surveys and interviews.

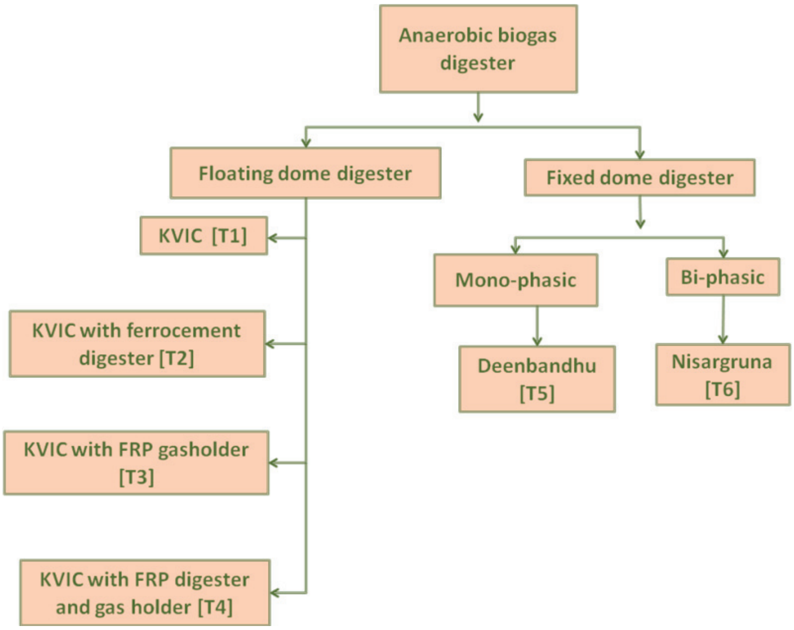

Fig. 1. Classification of biogas technologies used for AHP

3.2. Methodology for data collection from biogas plants

The various biogas plants data were collected through discussion with biogas owners and technology providers. A summary of the details is provided in the Table 2.

Table 2. Quantitative and qualitative attributes of various technology alternatives.

Attributes	Units	KVIC digester (T1)	KVIC digester with ferrocement digester (T2)	KVIC digester with FRP gas holder (T3)	KVIC digester with FRP digester and gas holder (T4)	Deenbandhu (T5)	Nisargaruna technology (T6)
Capital cost	Rs	11000	6000	8000	25000	7000	360000

Maintenance cost	Rs/year	299	200	150	100	150	24000
Skilled labor	Nos.	3	3	3	5	3	3
Unskilled labor for construction	Nos.	6	6	6	7	6	4
Time to set up	Days	5	5	3	3	4	45
Life of the plant	Years	10	12	15-20	25-30	12	10
Payback period	Years	4	2	4	6	4	
Energy Required/ Consumed	kWh/day	NR	NR	NR	NR	NR	3
Feed to water ratio	1	1	1	1	1	1	1 to 3
Raw material		Bricks, Concrete, Cement, Sand, M.S. Sheet	Bricks, Concrete, Cement, Sand, M.S. Sheet, M.S. Wire	Bricks, Concrete, Cement, Sand, FRP	FRP	Bricks, Cement, Sand	Mild Steel Sheets
Location		Village	Village	Village	Village	Village	City
Transport		Not transportable	Not transportable	Not Transportable	Tempo	Not Transportable	Truck
CH_4 content in the biogas	%	55-60	55-60	55-60	55-60	50-55	70-75
Sturdiness		Sturdy	Sturdy	Sturdy	Sturdy	Less Sturdy	Sturdy
Skills		Initial training is required	Initial training is required	Initial training is required	Initial training is required	In depth training required	Intense training required
Accessories required		none	none	none	none	none	Large no of accessories required
Degree of mechanization		Manually operated	Manually operated	Manually operated	Manually operated	Manually operated	Partially mechanized

	Means a qualitative attribute

3.3. Methodology for AHP

AHP involves three stages namely, decomposition, comparative judgment and synthesis of priorities. In the first stage of decomposition, a complex decision problem is decomposed into a hierarchy, each level consists of few manageable elements and these elements are again decomposed into another set of elements. This process helps in dealing with complexity and identifying the major components of the problem. For evaluation of the technologies, 7 attributes at Level 1 of the hierarchy represented by N1, N2,.. and 17 attributes at Level 2 of the hierarchy represented by A1,A2,A3,.. were identified (see Figure 2). The raw data about these attributes is given in the Table 2.

Table 3. Quantitative and qualitative attributes of various technology alternatives.

Level 2	Attributes	Units	Cost/ Benefit*
A1	Capital cost	Rs	Cost
A2	Maintenance cost	Rs/year	Cost
A3	Skilled labor	Nos.	Cost
A4	Unskilled labor for construction	Nos.	Benefit
A5	Time to set up	Days	Cost
A6	Life of the plant	Years	Benefit
A7	Payback period	Years	Cost
A8	Energy Required/ Consumed	kWh/day	Cost
A9	Feed to water ratio	1	Cost
A10	Raw material		
A11	Location		
A12	Transport		
A13	CH_4 content in the biogas	%	Benefit
A14	Sturdiness		
A15	Skills		
A16	Accessories required		
A17	Degree of mechanization		

Each of the attributes was further classified as qualitative and quantitative which are further grouped into two types (1) Benefit attributes, (2) Cost attributes as shown in Table 3. This depends on the perspective of the decision maker e.g. a decision maker who wants the regional self reliant development will consider the labour requirement as a benefit attributes, contrary to this a decision maker who is interested in minimizing the labour requirement in order to maximize the profits will consider this attribute as cost. In the second stage of comparative judgment an attribute to attribute comparison is carried out for getting the relative importance of one attribute over the other on the basis of scale of relative importance given by Saaty [9]. Attribute weights are obtained by doing pairwise comparison of the attributes based on the scales of importance through interviews conducted with expert including NGOs implementing biogas projects, biogas plant owners and government officers for various technological options. Based on the data obtained by raw data collected for quantitative attribute the quantitative attribute are defined as cost attribute or benefit attribute and accordingly its normalized values are calculated as per the procedure followed by Jain and Rao [10]. In the third stage, for ranking the alternatives following formula is used

$$R_j = \sum_{i=17}^{17} p_{ij} w_i \tag{1}$$

Here,
R_j = Ranking of the alternatives
p_{ij} = Normalised attribute values of the alternatives
w_i = attribute weight

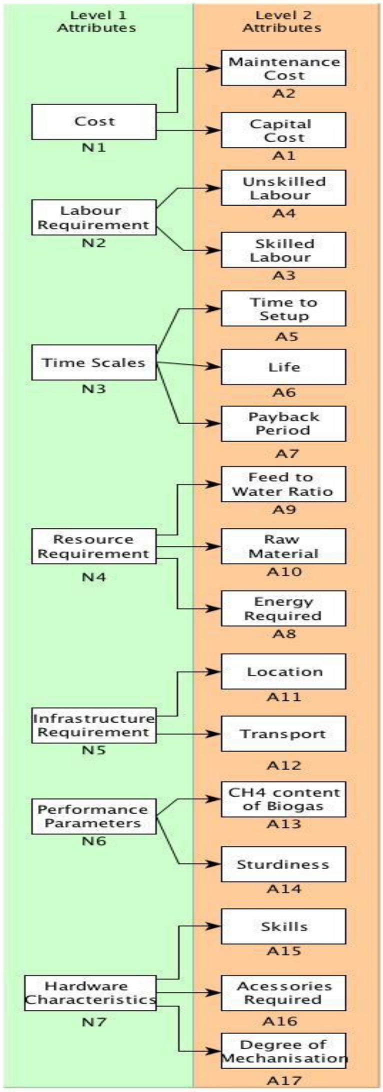

Fig. 2. Levels of AHP analysis attributes

4. Result of AHP Study

The priority vectors of all the 17 attributes are combined to form [P] (see Table 4), which is called as normalised attributes matrix. The overall attribute weights are also shown in the same table. The ranking of the alternatives is obtained by using Eq. (1). Higher the value of R_j, the better is the j^{th} alternative.

Table 4. Final attribute weights and Normalised attributes matrix.

Attributes	Weights	T1	T2	T3	T4	T5	T6
A1	0.17	0.99	1	0.99	0.95	1	0
A2	0.83	0.99	1	1	1	1	0
A3	0.17	1	1	1	0	1	1
A4	0.83	0.67	0.67	0.67	1	0.67	0
A5	0.18	0.95	0.95	1	1	0.98	0
A6	0.16	0.99	1	0.99	0.95	1	0
A7	0.14	1	1	1	1	1	0
A8	0.51	0.99	1	1	1	1	0
A9	0.07	0	0.1	0.5	1	0.1	0
A10	0.65	0.98	1	0.98	0.95	0.98	0
A11	0.28	0.21	0.21	0.21	0.21	0.08	0.02
A12	0.83	0.19	0.19	0.19	0.19	0.19	0.02
A13	0.17	0.4	0.08	0.08	0.08	0.08	0.02
A14	0.83	0.14	0.14	0.14	0.14	0.39	0.03
A15	0.17	0.19	0.19	0.19	0.19	0.19	0.02
A16	0.83	0.08	0.08	0.08	0.22	0.08	0.45
A17	0.17	0.19	0.19	0.19	0.19	0.06	0.19

The summary of rankings is shown in Table 5. FRP ranks first because of its corrosion resistance and hence less maintenance cost, has high strength to weight ratio which makes it easy to transport and improved life, and unskilled person with meager amount of training can also be employed in its construction and repairs hence meeting the goal of regional self reliant development.

Table 5. Ranking of the alternatives for the perspective of regional self reliant development.

Alternative	T1	T2	T3	T4	T5	T6
R*j*	3.83	3.81	3.83	4.05	3.97	0.60
Rank	4	5	3	1	2	6

Sensitivity analysis is carried out by elimination of different attributes. This is actually to see how ranking change if particular attribute does not play any significant role in technology selection. Here sensitivity analysis is carried out by eliminating the Level 1 attributes. The rankings for 8 cases are given in Table 6. In case 0 no attribute is eliminated 43 and in case 1 attribute N1, case 2 Attribute N2.........and in case 7 attribute N7 is eliminated respectively. The highest ranked alternative is found independent of the removal of attributes except Attribute N2: Labour attribute N6: Resource requirement and Attribute N7: Time scales.

Table 6. Results of sensitivity Analysis.

Alternative	T1	T2	T3	T4	T5	T6
Case 0: Default Ranking	3.8268	3.8091	3.8298	4.0522	3.9726	0.5974
Ranking	3	4	2	1	5	6
Case1: By eliminating N1	2.8368	2.8091	2.8315	3.0607	2.9726	0.5974
Ranking	3	5	4	1	2	6
Case2: By eliminating N2	3.1007	3.083	3.1037	3.2222	3.2465	0.4274
Ranking	4	5	3	2	1	6
Case3: By eliminating N3	2.9189	2.8945	2.9078	3.2528	3.0526	0.9709
Ranking	3	5	4	1	2	6
Case4: By eliminating N4	3.131	3.0933	3.099	3.3059	3.3062	0.5918
Ranking	3	5	4	2	1	6
Case5: By eliminating N5	3.6011	3.6378	3.6585	3.8809	3.8013	0.5774
Ranking	5	4	3	1	2	6
Case6: By eliminating N6	3.6783	3.6606	3.6813	3.9037	3.6166	0.5691
Ranking	3	4	2	1	5	6
Case7: By eliminating N7	3.7281	3.7104	3.7311	3.8373	3.8739	0.2205
Ranking	4	5	3	2	1	6

5. Conclusions

Analytical Hierarchical Process is used for ranking of the 6 biogas alternatives namely KVIC digester, KVIC with ferrocement digester, KVIC with FRP gas holder, KVIC with FRP digester and gas holder, Deenbandhu and Bi-phasic digester based on Nisargruna technology. The regional self reliant development accords the highest ranking to the technology KVIC with FRP gas holder and digester [T4]. The KVIC digester with FRP material [T4] is corrosion resistant and hence requires less maintenance cost, has high strength to weight ratio and hence easy to transport, and unskilled person with meager amount of training can also be employed in its construction and repair. In other terms, the rank of the technology KVIC with FPR digester and gas holder [T4] is sensitive to attribute Labor requirement (N2), Resource requirement (N4) and Time scales (N7). Nisargruna (T6) ranks last due to its high science based skills requirement, use of numerous accessories, power requirement for its operation, no potential to generate employment for unskilled labor, repair is difficult in locally and unbearable capital cost with high payback period. Thus, AHP can be used as an decision making tool for choice of biogas

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